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An Approach to Tone Reproduction for Converting Transparencies to Reflection Prints

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An Approach to Tone Reproduction for Converting Transparencies to Reflection Prints

By

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ABSTRACT

The purpose of this investigation was to study the useful criteria for converting transparencies to reflection prints, and examine the unavoidable departures from the criteria. A single useful criterion was found; that the relative brightness of the reproduction match those of the original. One significant compromise appeared to be in the shadow reproduction in low maximum density reflection prints. It was found that like reflection prints, transparencies do not typically reach relative brightnesses as low as zero. Thus, only a relatively small departure from the 1:1 criterion was likely . Flare in the camera system and viewing conditions limits the maximum density in transparencies to less than sensitometric curves indicate. A simple method for plotting transparency-to-print reproduction was proposed that encorporates the 1:1 relative brightness criterion.

INTRODUCTION

To begin an investigation of the tone reproduction requirements of a transparency-to-reflection print system two questions can be asked:

1) What are the useful criteria for reproduction?
2) What are the compromises when the desired criteria cannot be achieved?

The purpose of this investigation, then, was to study existing proposals for converting a transparency to a reflection print, to discern what deviations from the criteria were likely, and to select one such unavoidable departure from the suitable criteria for a study of the optimum compromise. One proposal by C. J. Bartleson and E. J. Breneman for optimum reproduction appeared to be a single satisfactory criterion; that the relative brightnesses of the reproduction should match those of the original.[1] An examination of this requirement indicated that a low maximum density reflection print system might not be able to reproduce the shadows of a transparency according to the relative brightness criterion. The focal point of investigation then became the determination of the optimum compromise for the shadows. Before dealing with this specific problem a discussion of various proposed approaches to tone reproduction is in order.

THEORY

One early proposal for tone reproduction was the concept of facsimile reproduction. Here the density values of the reproduction equal or are directly proportional to the corresponding densities in the original. Figure 1 illustrates this. This criterion is applicable in certain situations. For example, facsimile reproduction would be a suitable aim for copy negatives or for duplicate transparencies. However, when the original is a transparency and the reproduction is a reflection print, facsimile density reproduction is no longer even remotely obtainable. A reflection print might typically reach a maximum density of 1.6 while the maximum density in a transparency can easily exceed 2.0. If facsimile density reproduction was the correct criterion for handling transparency-to-print reproduction then the obviously large failure of reflection prints to achieve the same density range as transparencies should correlate with a large inadequacy of the print to resemble the original transparency. Yet the tones rendered in a reflection print certainly can be a reasonable match to the tones of the corresponding transparency. That the eye perceives the print and the transparency as similar even though the densities of the print and the transparency are significantly different is evidence that visual perception is not merely linearly dependent on the densities or log luminances of a scene. The phenomena of visual adaptation are therefore an important consideration in approaching tone reproduction of transparency-to-print systems.

The term brightness describes the visual sensation produced by light. Thus, brightness estimates by an observer are estimates of the magnitude of visual sensation produced by light. Perceived

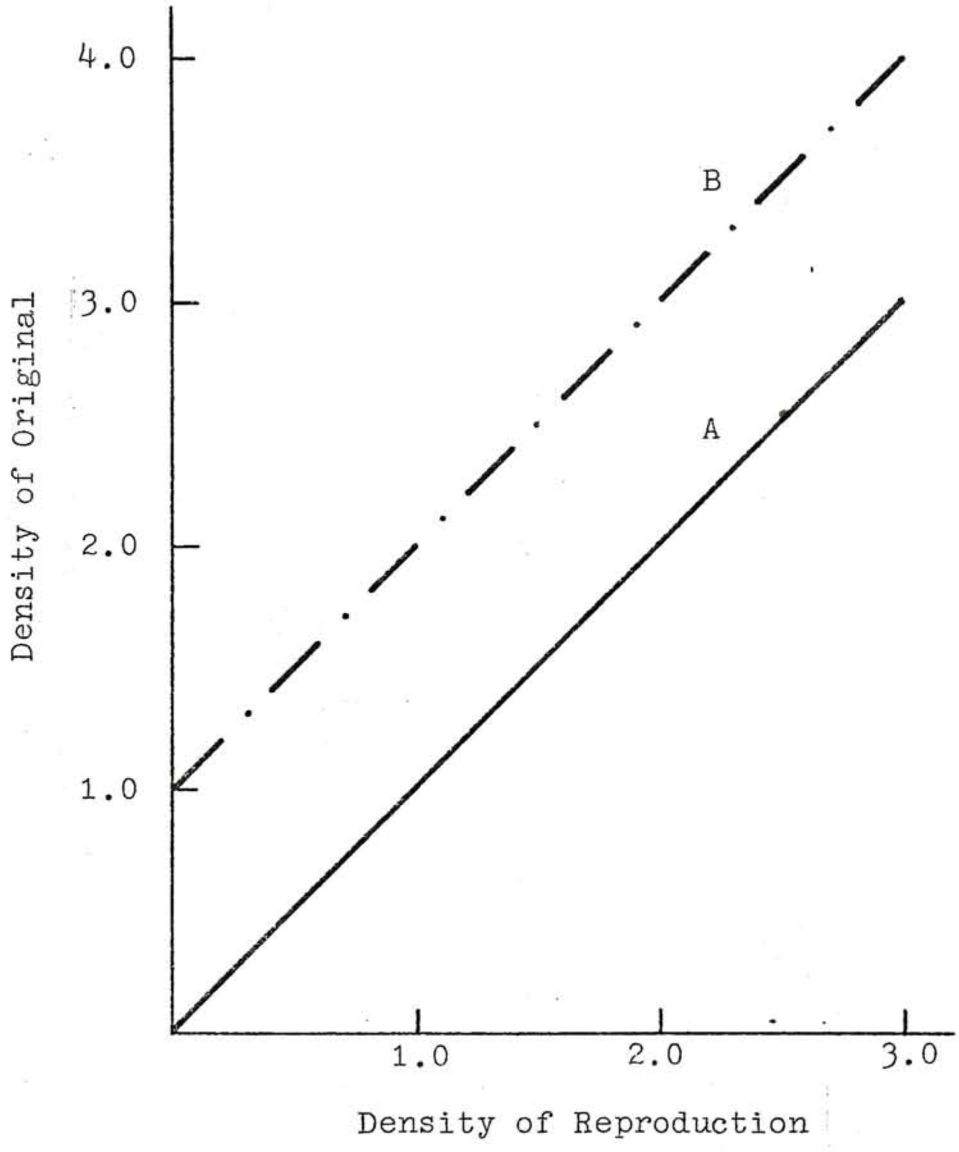


Figure I. Curve A is a straight line with a slope of 1.0 and is the case where densities of the reproduction equals the densities of the original. Dashed line B also has a slope of 1.0 and is an example of where densities of the reproduction are proportional but not equal to densities of the original.

brightnesses in a scene are dependent on our visual adaptation to the scene. One aspect of visual adaptation is called direct adaptation. Another is lateral adaptation. Direct adaptation describes the ability of the eye to adjust its sensitivity to different average luminance levels. Direct adaptation can take several minutes. The discomfort associated with turning on lights after having been in a dark room is an example of the eye in the process of direct adaptation to a much higher average luminance level. There are, of course, limits to direct adaptation. These limits account for the fact that objects under moonlight do not appear as bright as they do in sunlight. Likewise, without any adaptation capabilities the eye would simply not function over the extreme range of different luminance levels presented by viewing conditions as diverse as moonlight and sunlight. Lateral adaptation is where an observer's perception of the brightness of a particular scene element is affected by the luminances of areas surrounding that element. The photograph in figure 2 illustrates the effect of lateral adaptation. This photograph was exposed and processed so that the densities of the two circular elements in the image are equal. Hence, the luminances of both circles are also the same (assuming that the reader is viewing the print under even lighting conditions). Yet the perceived brightnesses of the two circles are not equal. The solid dark area immediately surrounding the one circle and the solid light surround about the other affect our perception of brightness so that the dark surrounded circle appears brighter. This phenomenon is now widely recognized, and it obviously complicates the issue of tone reproduction. Consider the fact that a reflection print is typically viewed with light surround while transparencies are usually projected in a dark surround. Different conditions of lateral adaptation are therefore present in the two media so that the optimum reproduction relationship between the transparency and print must now take into account the surround effect.

SEARCH FOR A SUITABLE REPRODUCTION CRITERION

For reasons previously stated, facsimile density reproduction was quickly rejected in search for an acceptable reproduction criterion. Another proposal for tone reproduction is to plot the curves in terms of Munsell value.[2] The Munsell value scale was the result of one of the original brightness scaling experiments. The Munsell values represent equal visual differences between tones (under specified viewing conditions). Rhodes suggested that plotting in terms of Munsell value rather than linear density scales was more meaningful since Munsell values correspond more closely to the visual response characteristics of the eye. Plotted according to Munsell values, the tone reproduction criterion would again be a 45^{o} straight line relationship. Yule describes a special graph paper which allows density values to be plotted directly on a scale corresponding to linearly spaced Munsell values.[3] The ordinate and the absissa of figure 3 indicate the required compression of the density scale to give equally spaced Munsell values. In figure 3 curve A is the desired reproduction aim. Curve C was the result of investigation into optimum halftone reproduction by Yule in 1968.[4] In this investigation the straight line compression of values along curve B was found to be less satisfactory than curve C for accuracy of reproduction. It is important to realize that Yule's study was of a system where both the original and the reproduction were reflection prints. Thus, the reproduction is viewed under essentially the same lighting conditions as the original (i.e., a light surround). Yule makes no extrapolation of his experimental data to include a transparency-to-print reproduction cycle. However, in this context Sunderland apparently uses curve B as his reproduction aim.[5] His justification for using this curve is not clear.

We have concluded that the Munsell coordinate method is not useful for plotting transparency-to-print reproduction because the brightness perception scaling is the same for both the y axis and the x axis. However, the lateral adaptation to the transparency in its dark surround and to the print in light surround alters the visual response characteristic of the eye. Therefore, to plot the transparency and the print on scales which assume equal visual adaptation would be in error. To verify this, empirically determined data for an optimum transparency and the optimum preferred print of the same subject were used. The empirical results were determined in an investigation by Nelson.[6] Figure 4 shows the characteristic curves for a transparency viewed in dark surround (curve A), a transparency viewed in light surround (curve B), an optimum reflection print accomplished with special emulsion and low flare viewing conditions (also curve B), and an optimum print with typical photographic paper and viewing conditions (curve C). The experimental print paper yielding curve B was preferred to curve C prints. When density values of B were plotted versus those of curve A on the Munsell graph paper the relationship in figure 5 resulted. This is clearly a departure from the curves used by Yule and Sunderland. Moreover, the shape is certainly not an easy reproduction aim curve to use in practice.

After investigating the Munsell coordinate system it was finally obvious that brightness perception data relating to the respective viewing conditions of transparencies and prints was needed. Fortunately, several researchers have made continuing efforts to study brightness perception, a subject in which repeatable data is difficult to achieve. Among these studies are the work of Bartleson and Breneman,[7] Hartline,[8] Hunt,[9] Jameson and Hurvich,[10] Marsden,[11] Stevens,[12] and others. Nelson has compiled an approximate average of the brightness versus log luminance results for many workers.[6] The family of operating curves for brightness versus log luminance shown in figure 6 presents this average data. Note that the different operating curves are the result of direct adaptation. Also note that the curve shapes are approximately the same over a large range of average luminance levels and that lateral adaptation, the effect

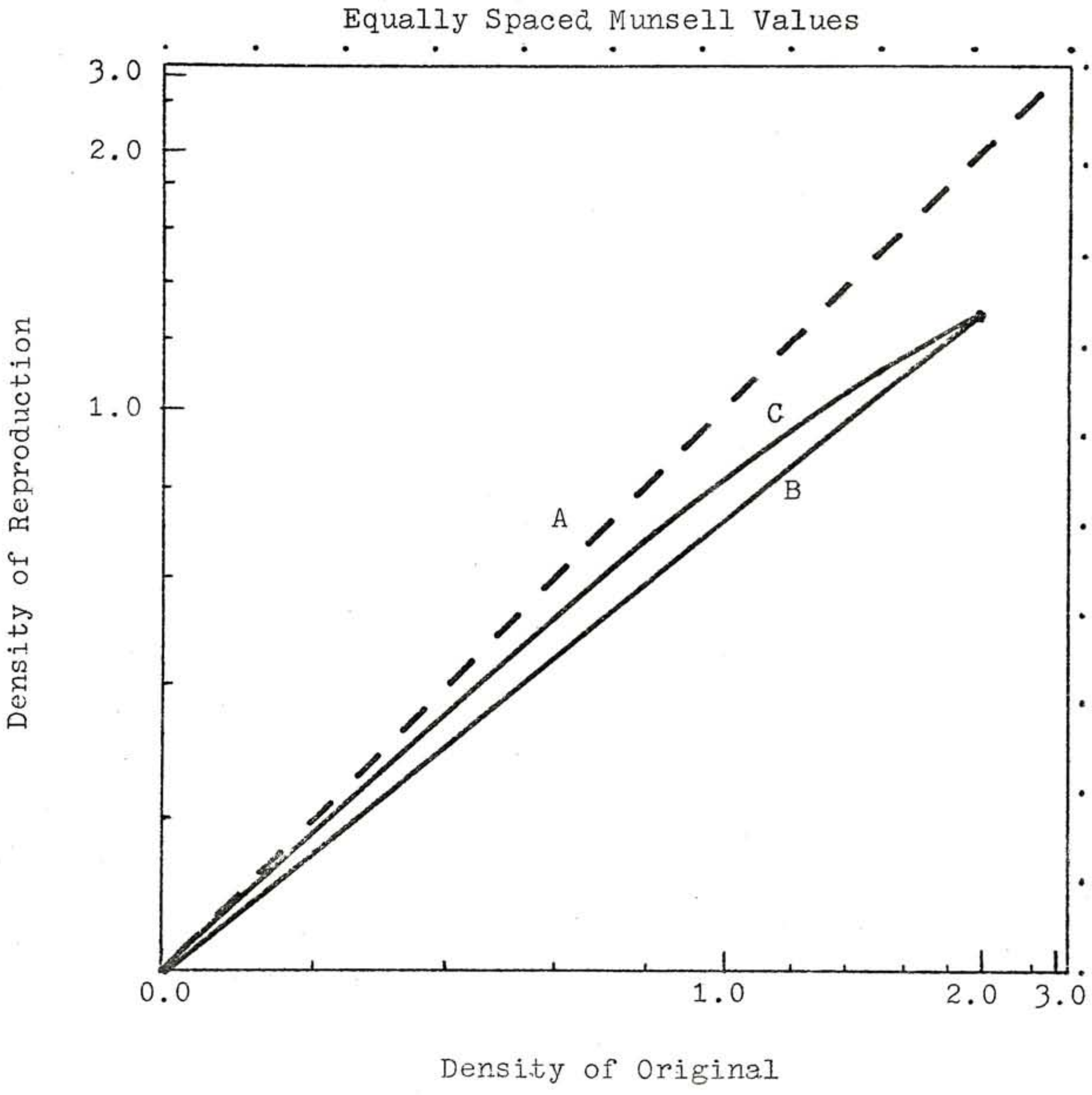


Figure 3. Tone reproduction graph paper with density scales corresponding to linearly spaced Munsell Values.

* Yule, J. A. C. (1968). 'Plotting Tone Reproduction Curves,' Rochester: Graphic Arts Research Center, 1968.

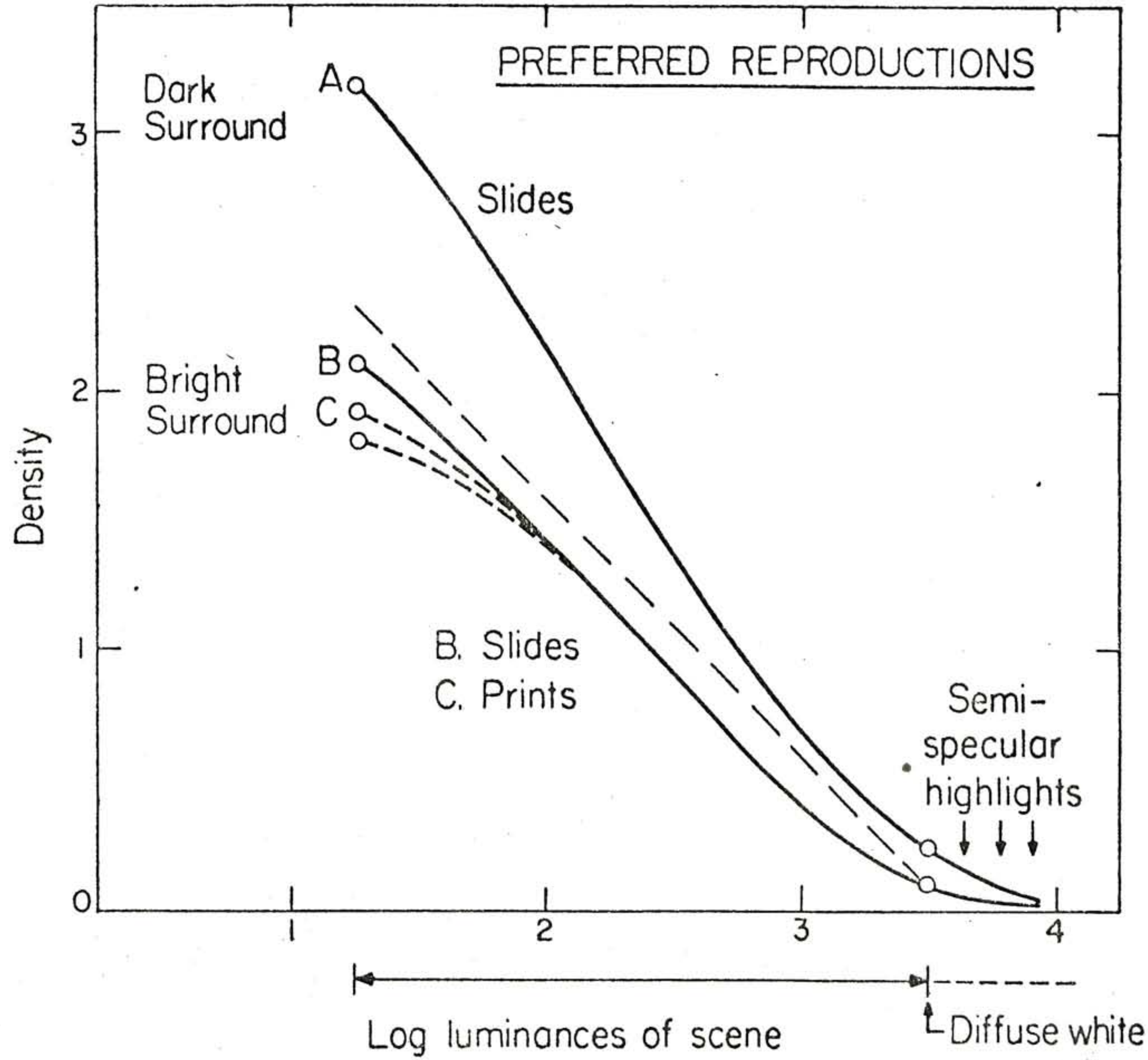


Figure 4.

* Nelson, C. N.; ''Tone Reproduction and Visual Adaptation,'' SPSE Visual Encyclopedia

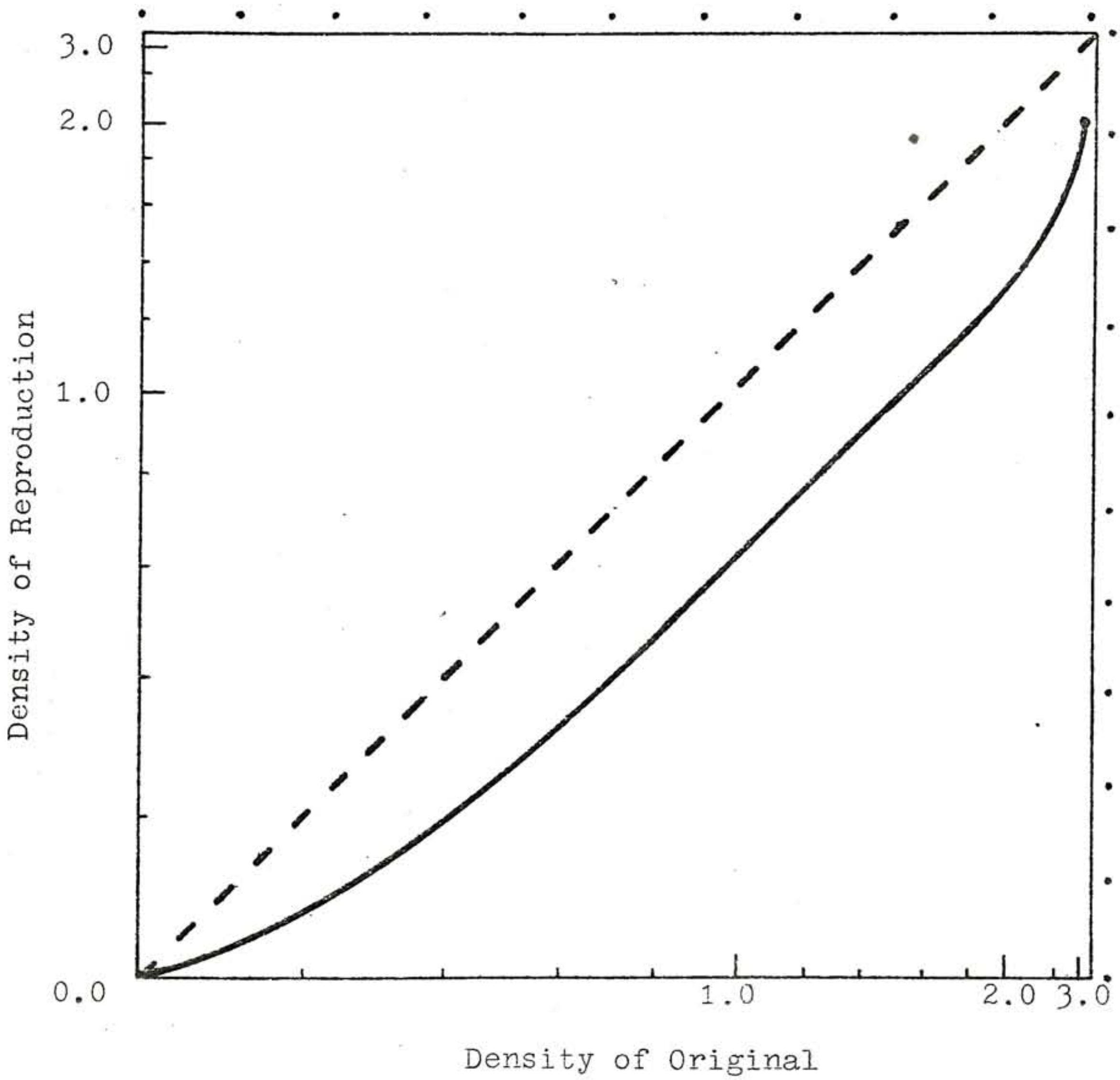

3.0
2.0
1.0
0.0
1.0
2.0 3.0
Density of Reproduction
Density of Original

Figure 5.

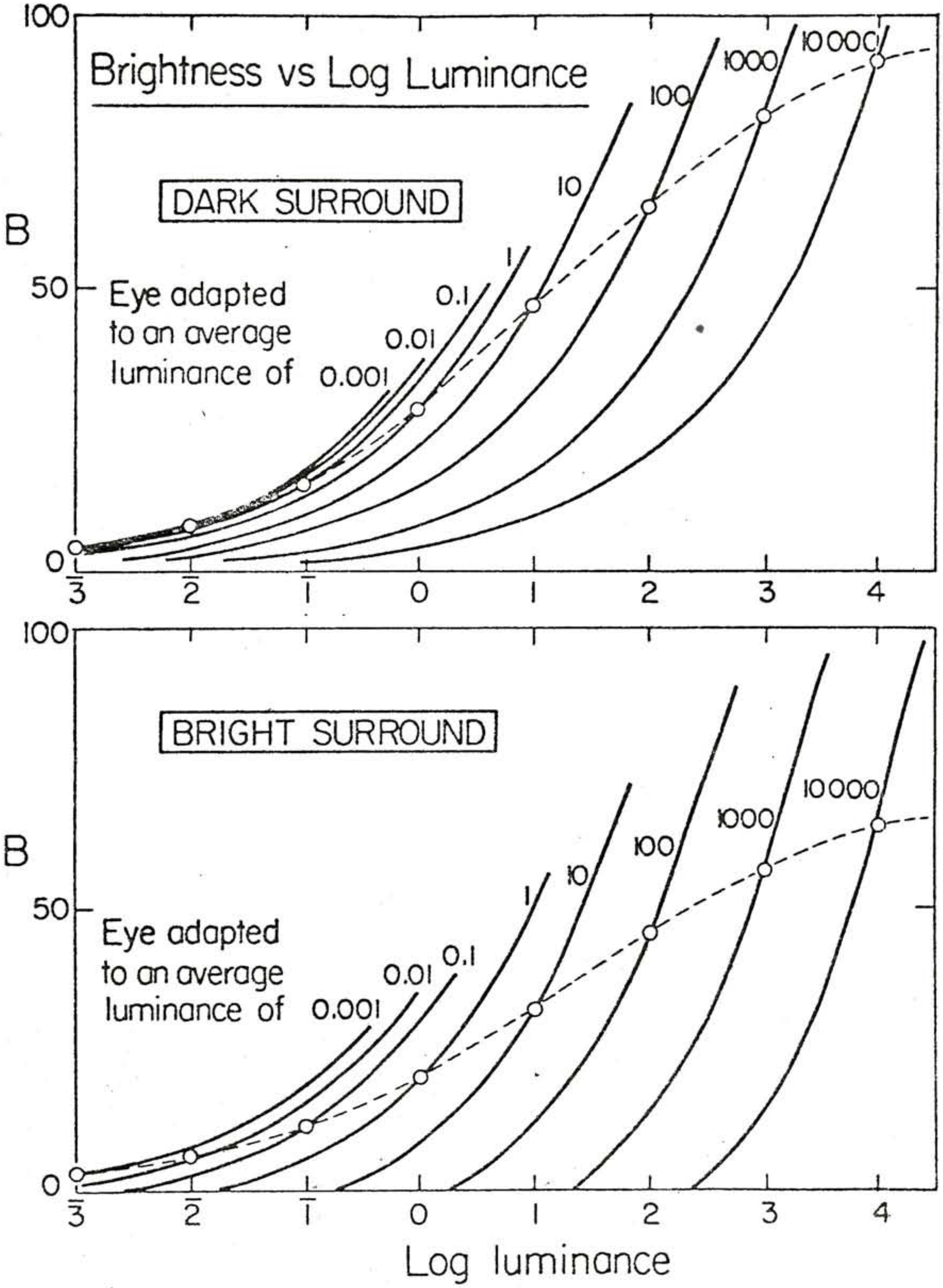


Figure 6.

* Nelson, C. N.; 'Tone Reproduction and Visual Adaptation,' SPSE Visual Encyclopedia

of the surround, appears to place the eye response on different portions of the operating curves. The brightness scale shifts upwards along the curves in the bright surround conditions.

In figure 6 the dashed lines connect points on the curves denoted by small circles. These points mark the coordinates of a scene element having the average luminance value of that scene. Note that an element with luminance equal to the average luminance of the scene increases in brightness as the average luminance level rises. This describes an obvious fact. As mentioned earlier in this report, objects certainly appear brighter in sunlight than in roomlight or moonlight. However, consider normalizing the absolute brightness values between zero brightness and that brightness value corresponding to the scene highlight for different levels of illuminance. Bartleson and Breneman proposed this idea of a relative brightness scale.[1] They found that by assigning a relative brightness value of 100 to a reference white in the scene and then normalizing absolute brightness data about that reference white, the relative brightness values remain fairly constant over a wide range of illuminance levels. Although absolute brightness values vary considerably with levels of illumination, relative brightness values do not. On the other hand, relative brightnesses do change significantly for different surround conditions (i.e., dark, dim, light surround). These facts are summarized in an investigation by Bartleson and Breneman in 1962.[13]

Since the luminance values of prints and transparencies are generally quite different from the original scene luminances absolute brightness reproduction is not achieved. As stated earlier Bartleson and Breneman proposed that 1:1 relative brightness reproduction was the tone reproduction aim.[1] The fact that relative brightness curve shapes remain essentially constant except for different surrounds allowed Bartleson and Breneman to specify equations for relative brightness under three general surround conditions typically encountered:[14]

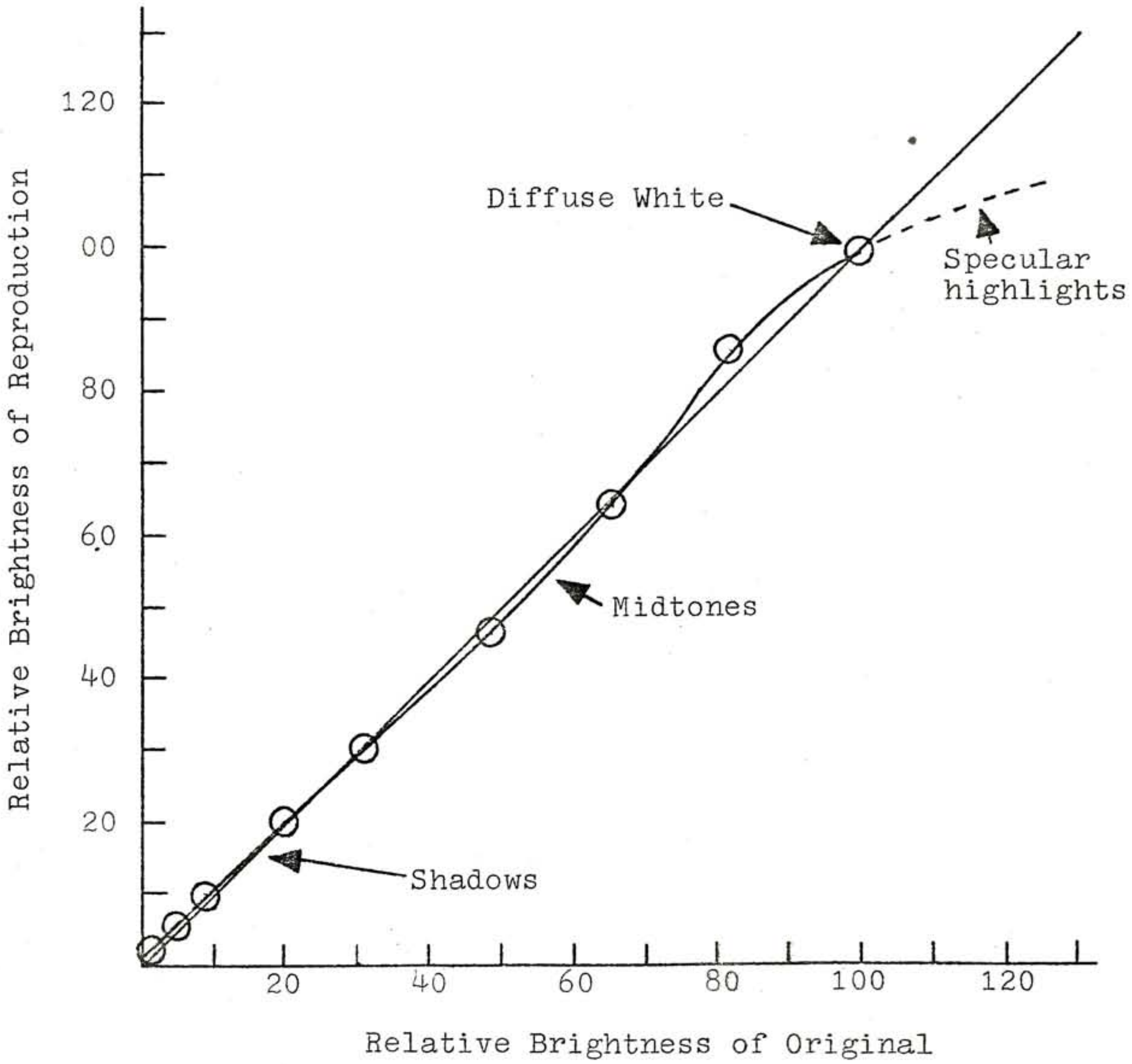
1) L^{**} (light surround) $= 11.5(100Y/Y_o + 1.0)^{0.50} - 16$

2) L^{**} (dim surround) $= 17.5(100Y/Y_o + 0.6)^{0.41} - 16$

3) L^{**} (dark surround) $= 25.4(100Y/Y_o + 0.1)^{0.33} - 16$

L^{**} is Bartleson's and Breneman's notation for relative brightness. The term $100Y/Y_o$ equals the relative luminance of a scene element. Y is the luminance of the particular scene element and Y_o is the luminance of the reference white. The use of these equations will be discussed in detail in the experimental section of this report. Equation 1) is useful for analysis of reflection prints, equation 2) for television viewing, equation 3) for transparencies. There are two particular advantages to these equations compared to the Munsell system. First, they consider the effects of lateral adaptation. Second, the absolute brightness data which was normalized in these equations was determined for complex field viewing conditions rather than simple field viewing conditions. Simple field data represents brightness scaling experiments where the observers judge brightness of single patches on a single surround luminance. Brightness perception using complex stimulus configurations such as photographs is different than for simple field stimuli. The term complex field describes the fact that photographs are not just one tone surrounded by another tone but typically are a random spacing and arrangement of many elements with varying tones. Thus, the proposal of 1:1 relative brightness reproduction appears to be a suitable criterion for converting a transparency to a reflection print. It can be implemented using equations 1) and 3) which will more adequately account for the effects of visual adaptation compared to the previously mentioned tone reproduction methods.

To verify the usefulness of equations 1) and 3) we again resorted to the empirically determined characteristic curves A and B of figure 4. If a 1:1 relative brightness relationship exists between a transparency and the original scene and between the print and the original scene, then it follows that the relationship between the transparency and print should also remain 1:1 relative brightness reproduction. Since curves A and B represent an optimum transparency and an optimum print then, using equations 1) and 3) appropriately, the relative brightnesses of the print versus transparency should exhibit a 1:1 correspondence. Figure 7 shows the results and confirms the usefulness of the equations. A 45° straight line relationship is very nearly achieved by the experimental data. The diffuse white points shown on curves A and B of figure 4 were assigned as the reference whites(ie., relative brightness set equal to 100).



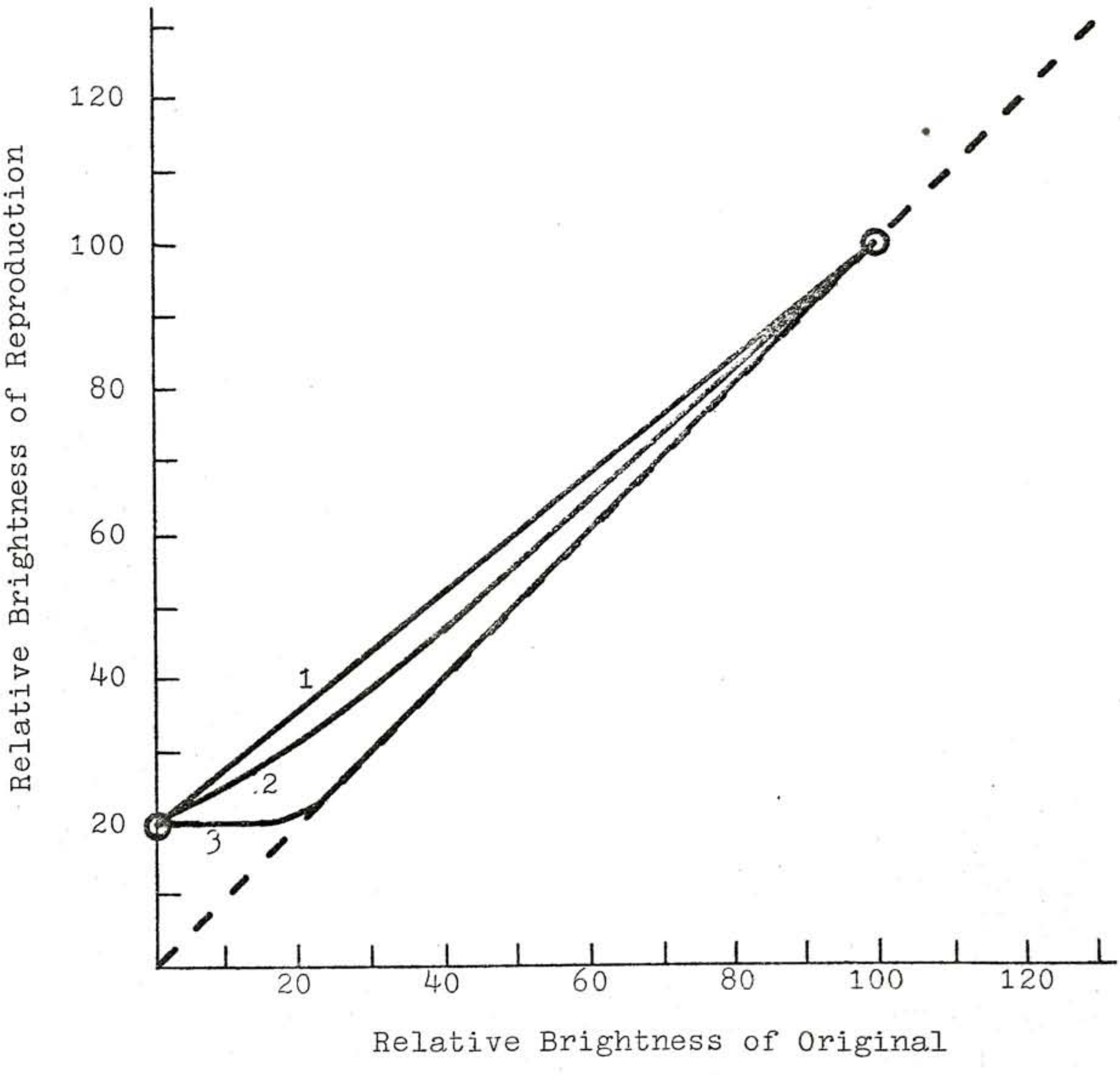
120
00
80
6.0
40
20
Relative Brightness of Reproduction
Diffuse White
Specular
highlights
Midtones
Shadows
20
40
60
80
100
120
Relative Brightness of Original

Figure 7.

DEPARTURES FROM THE CRITERION

Since the diffuse white points in the transparency and print were assigned L** values equal to 100, the specular highlights of the scene would have L** values greater than 100. Reflection prints cannot record as great a luminance range of specular highlights as transparencies. Therefore, specular highlights contained in the transparency cannot be reproduced according to the 1:1 brightness criterion. The dashed curve in figure 7 illustrates the resulting departure from the 45° straight line in the specular highlights. Indeed, the slight bow in the curve between values of 70 and 100 indicates difficulty with reflection prints in reproducing the highlights in general. Thus, highlight reproduction in a transparency-to-print system, particularly the specular highlights, suffers a compromise of the 1:1 brightness criterion.

Figure 7 shows accurate reproduction of the shadows. However, the characteristic curve B of figure 4 which was used to derive the figure 7 relationship represents a reflection print not found in practice. The shoulder of the characteristic curve B is not present even at a density of 2.0. Most reflection prints reach a maximum density under 2.0. Glossy photographic prints have a maximum density of approximately 2.0, but typical maximum density values for reflection prints are 1.2 to 1.6. According to equation 1) a reflection print process capable of 1.2 maximum density would reach a minimum relative brightness of approximately ~~20~~ 16. Thus a departure from the 1:1 relative brightness criterion is possible in the shadows also. Figure 8 illustrates departures in the shadow



Relative Brightness of Reproduction
120
100
80
60
40
20
1
2
3
20
40
60
80
100
120
Relative Brightness of Original

Figure 8.

reproduction with a reflection print which cannot reproduce relative brightness values below 20. Curves 1 and 3 are a logical assumption of the boundary shapes for the optimum compromise curve. Curve 1 and curve 3 might be the desired optimum compromise, or a curve shape lying between these such as curve 2 might effect the best compromise.

Various reproduction criteria have been discussed. Bartleson's and Breneman's relative brightness equations have been found to be the most suitable method for establishing the tone reproduction relationship applicable in a transparency-to-print system. Specular highlights in a transparency invariably lead to a compromise in the reproduction. Low maximum density prints can lead to a compromise situation if relative brightness values exist in a transparency which are lower than the minimum achievable L** value in the print. From these conclusions, one useful experimental study would be to determine the optimum curve for shadow reproduction in low Dmax reflection prints.

EXPERIMENTAL

The objective of our experimental work was to determine the optimum curve shape for shadow reproduction in low Dmax reflection prints. It was decided to investigate the three curve shapes of figure 8. Curve 1 is a straight line departure from the 45° straight line departure. A print having curve 3 characteristics would reproduce relative brightness according to the criterion down to a minimum L** value. Relative brightnesses in a transparency less than this minimum value would be indistinguishable in the print. Curve 2 is a compromise between

1 and 3. The middle tones would be reproduced more closely to 1:1 than for curve 1 and there would be some modulation of transparency brightnesses down to zero.

It is obvious that high key transparencies, ones containing no high densities, would not create the problem of shadow reproduction. For example, a transparency containing no relative brightness values lower than 40 would not be a reproduction problem to a print process capable of achieving minimum brightness values on the order of 20. The problem of reproducing the specular highlights remains, of course. Therefore, in this investigation low key transparencies, ones with predominately high densities, or full range density transparencies were needed. The experimental work focused on producing sets of transparencies and prints related to one another as in curves 1, 2, or 3. Psychophysical testing would then be used to determine the preferred curve shape.

Equations 1) and 3) can be modified to compute L** using relative density values rather than the Y/Y_o term. For an image element i, reference white, o:

Let density of i = D_i

Let density of o = D_o

Relative Luminance $L = \frac{100Y_i}{Y_o}$ where Y_i is the luminance of element i, and Y_o is the luminance of the reference white.

$$-(\log Y_i - \log Y_o) = (D_i - D_o)$$

$$-\log(Y_i/Y_o) = D_i - D_o$$

$$Y_i/Y_o = \frac{1}{10^{(D_i - D_o)}}$$

Therefore, $L = \dfrac{100}{10^{(D_i - D_o)}}$

The term $(D_i - D_o)$ can be called the relative density, D. It can be seen that the relative density of the reference white $(D_o - D_o)$ equals zero. Since the diffuse white points in the transparency and print have been assigned as the reference whites it is important to realize that specular highlights must then be regarded as having negative relative densities. Equations 1) and 3) can now be written:

1) L^{**} (light surround) $= 11.5(100/10^D + 1.0)^{0.50} - 16$

3) L^{**} (dark surround) $= 25.4(100/10^D + 0.1)^{0.33} - 16$

Figure 9 shows the plot of relative brightness versus relative density and a table of values computed by equations 1) and 3) is listed in the APPENDIX.

Making the Transparencies and Prints:

Six original transparencies were desired for the psychophysical tests. For each transparency three reflection prints

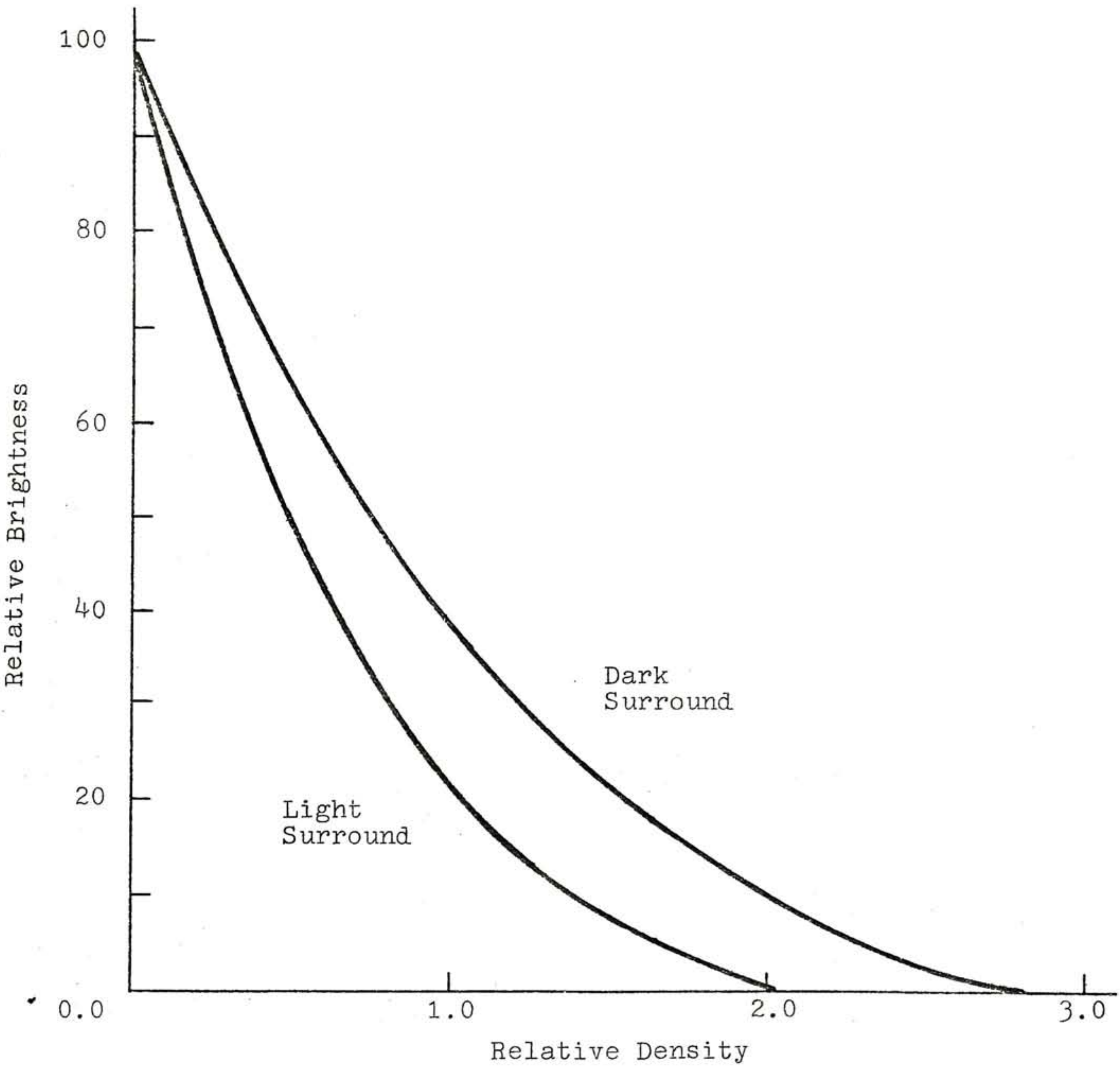

100
80
60
40
20
0.0
1.0
2.0
3.0
Relative Brightness
Relative Density
Dark
Surround
Light
Surround

Figure 9.

would be made having the three required relationships to the transparency shown in figure 8. Ranking experiments would be made. Observers would rate the prints on the basis of accuracy of reproduction by comparing the prints in light surround conditions to the corresponding transparency in dark surround conditions. The observers would be asked to judge the "accurate" reproduction as opposed to "preferred" reproduction for the following reasons. Accurate and preferred reproduction may differ due to the choice of compromises unavoidable in the reflection print. For example, in order to achieve more accuracy in the specular highlights an observer might choose a print that is darker overall than one he would prefer to view. The "accuracy" and "preferred" criteria might lead to different results for a second reason. Forced to judge accuracy of reproduction, it is more likely that the observer would confine his evaluation strictly to the appearance of the transparency and not form an impression of how the original scene might have been different. It is possible that a preferred print might be inadvertently correcting for deficiencies existing in the transparency's recreation of the original scene. Then, too, the observer might have certain biases unable to be accounted for. It is also possible that observers could be cautioned to treat the transparency independently of any beliefs about what the original scene looked like. In this case differences in ranking results for accurate prints and preferred prints would depend only on the choices of compromises in the reflection prints.

However, to simplify the experiment observers would be asked to judge accuracy of reproduction only.

Six transparencies were sought having the following qualities:

1) Three transparencies would be scenes of full tonal range such as outdoor sunlight scenes. Both highlights and dark shadows would be recorded.

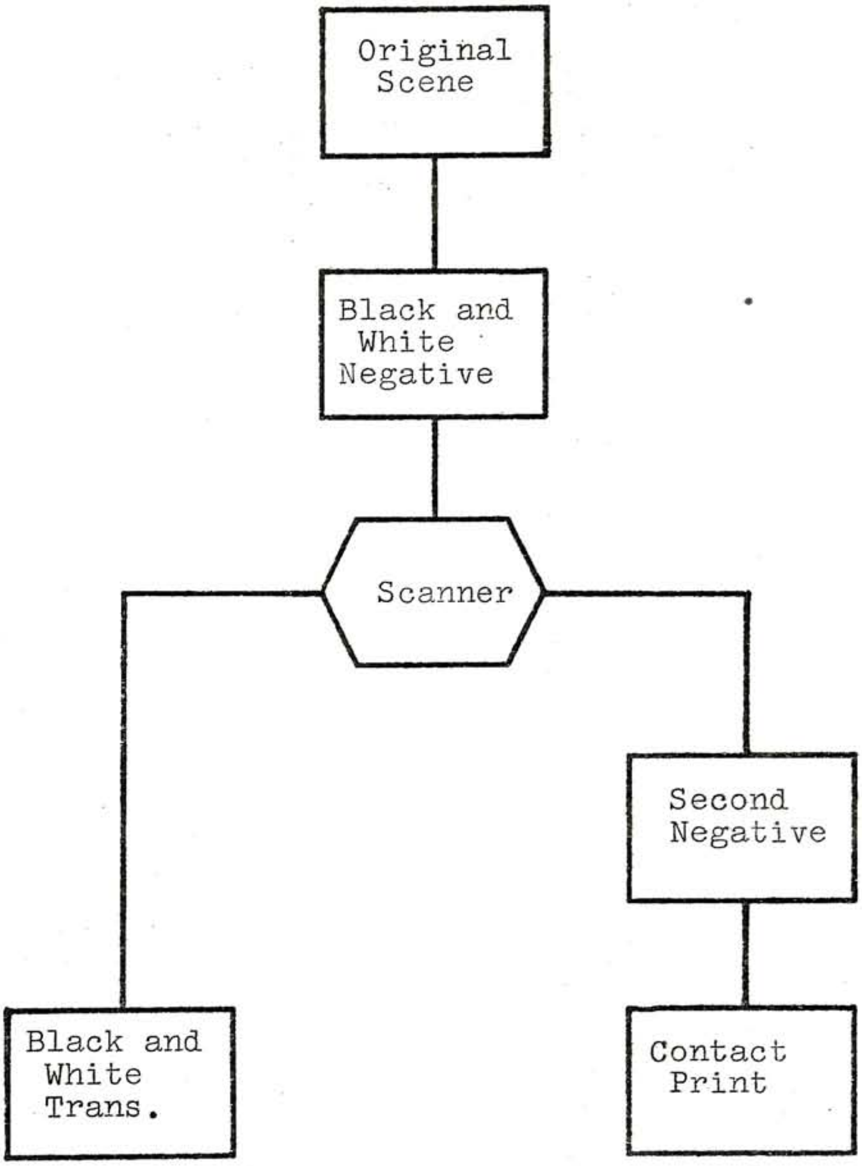
2) Three transparencies would be low key scenes having extensive shadow areas.

3) All transparencies would have:

   A) excellent sharpness and fine grain.
   B) interesting scenes to ensure that the transparencies would not be disliked by the observers.
   C) scenes representative of subject matter frequently encountered.
   D) correct exposure and characteristic curve shape closely approximating curve A of figure 4.

Transparencies are almost always color images. The time, cost, and difficulty of an investigation using color photographic materials was prohibitive. Black and white reflection prints from color transparencies would greatly confuse the psychophysical testing. Therefore, it was determined to use black and white transparencies. A good correlation between color and black and white tone reproduction has been found which justifies this decision. Research by Hunt, Pitt, and Ward[15, 16] on the tone reproduction characteristics in color photographic systems is in close agreement with Nelson's black and white data presented in figure 4.

The method employed for producing the transparencies and prints can be best explained using a block diagram (see figure 10). In figure 10 "Scanner" refers to an Enlarging Screening Separating Vario Chromagraph type C2-86 made by Hell-Color Metal Corporation. Using this instrument characteristic curve shapes can be manipulated to achieve the desired reproduction aim. Briefly, the scanner has a group of collection optics which scans an image (in either transmission or reflection mode) at 500 or 1000 lines per inch. The densities in the image modulate the output of a glow lamp. The lamp is focused as a small point source onto a film loaded in the machine so that a new image is "drawn" by the scanner. By adjusting voltages applied to the lamp as the collection optics read the transmittance or reflectance of particular image elements, these elements can be reproduced on the scanner film at desired density levels. The scanner can produce either negatives or positives. Thus, a camera negative with a particular characteristic curve could be scanned so that a positive transparency with the desired curve shape would result. Then, the negative could be scanned again to produce a second negative having a specific characteristic curve. The curve shape of the second negative would be calculated so that a contact print of this negative onto a selected photographic print paper would yield a positive reflection print related to the positive transparency in the desired manner.



Original Scene
Black and White Negative
Scanner
Black and White Trans.
Second Negative
Contact Print

Figure 10.

The Camera System:

The experimental work began by photographing suitable original scenes. The original scenes were recorded with an 8 x 10 view camera. This format was selected for the following reasons:

1) The image size and sharpness was necessary due to the number of steps in the proposed reproduction method.

2) The large image size made the reproduction less susceptible to degregation by dust and scratches.

3) The problems attendant with image enlargement were avoided.

4) Density readings of elements in the image were greatly simplified. Densitometer aperture discs with diameters less than 2mm were not necessary.

Kodak Plus-X Pan Professional film type 4147 was selected as the negative material. A special double dark slide was constructed which allowed a grey scale exposure at the bottom. The image dimensions of the scene became 7 x 10 inches allowing a 1 inch strip at the bottom for the grey scale data. The scene was photographed first with one part of the special dark slide in place. Then the grey scale was placed at a distance where a one stop increase in exposure was used to compensate for the bellows extension. The second part of the dark slide was in position at this time. Thus, two independent exposures could be placed on the 8 x 10 inch film sheet. The grey scale method was only an approximate way of determining the camera characteristic curve. A series of telephotometer luminance readings of elements within the scene would have been a more accurate method of estimating the density versus log luminance curve for each negative. The approximations in the image density versus scene log luminance data for the negatives meant that uncertainties in the curve shape of the scanner produced positive transparencies would exist. This was the major reason for confining the psychophysical testing to the accuracy criterion. Uncertainties in the curve shape of the transparencies would not present a problem in determining the transparency-to-print relationship since only corresponding densities in the images are involved in calculating this.

RESULTS

Two negatives of suitable scenes were initially produced. It was decided to follow through with the scanner reproduction cycle illustrated in figure 10 in order to ascertain the workability of the method. When the scanner film, Dupont type CSS-1, was processed for the recommended time, a density range of about 2.0 resulted. The scanner can only manipulate curve shapes between the density levels attainable in the film processing. A 3.0 density range was required to produce the desired transparency curve. It was determined that by doubling the developer concentration and processing for approximately twice the recommended time, a density range of about 2.9 resulted. The desired 3.0 range could not be attained because the base + fog level began to rise more than the Dmax level at higher concentrations and/or processing times. However, a range of 2.9 was acceptable.

The first image was then scanned. Several attempts were necessary, but the curve shown in figure 11 resulted. The diffuse white in the image was produced at 0.23 above base + fog as desired, and the shadow densities were acceptable though not ideal. The shape of the curve at densities lower than the diffuse white could not be controlled by the scanner without sacrificing the required control over the shadows. The specular highlights looked quite acceptable in the scanner produced transparency, and it was therefore assumed that the curve shape in the specular highlight region did not depart seriously from the aim curve.

The second negative was then scanned. For unknown reasons the repeatability and refinements in scanner technique achieved in the trials of the first transparency did not carry through into the making of the second transparency. On the contrary, more trials were necessary with the second transparency. Finally, a curve shape in the region of densities above the diffuse white point was achieved which was nearly identical to the first transparency. However, the specular highlights were unacceptably reproduced. Scanner control in the specular highlight portion of the curve which was not needed in producing the first transparency was now a necessity in the production of the second transparency. The dashed curve in figure 11 illustrates the poorly reproduced specular highlights of the second transparency.

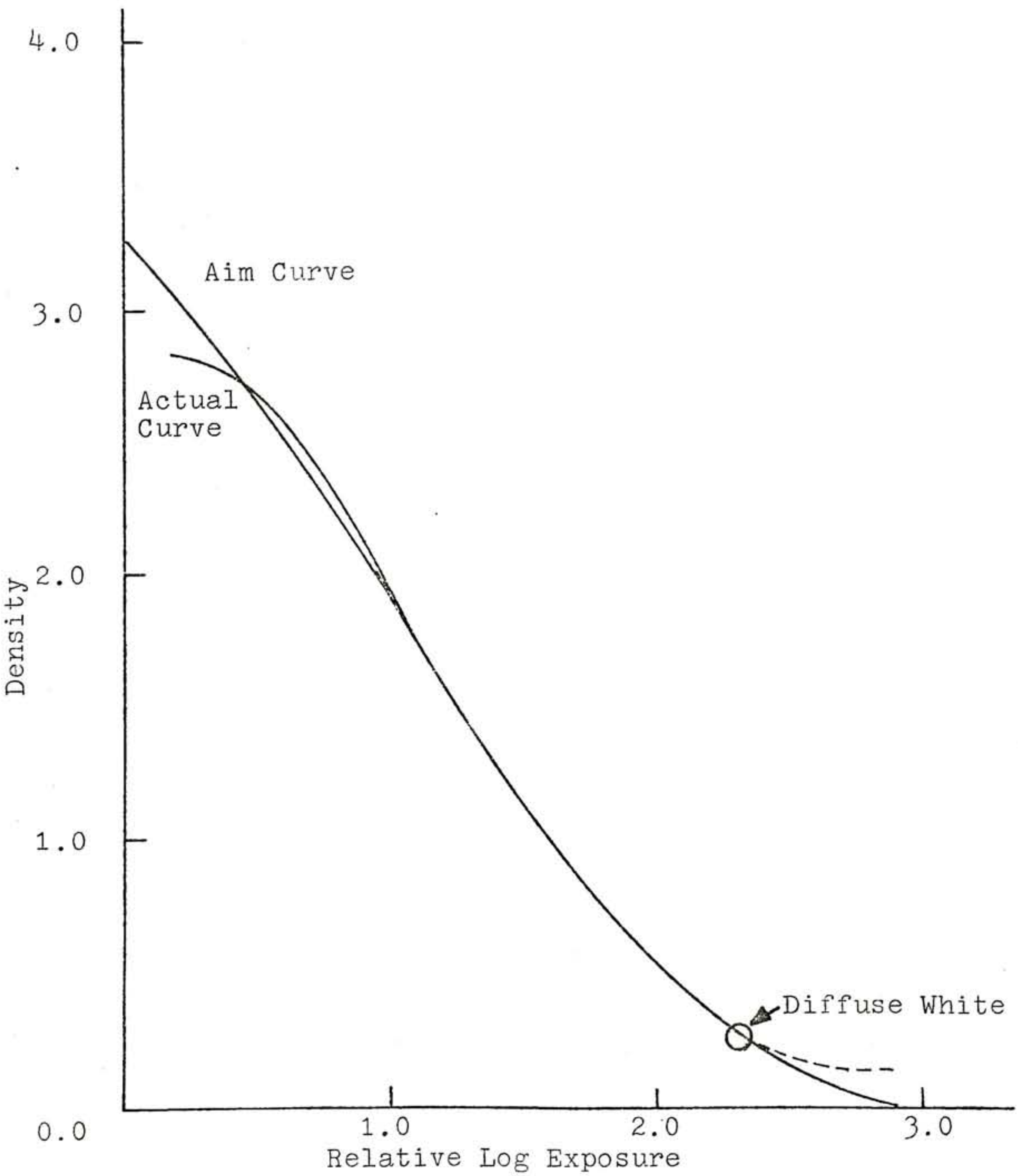

4.0
3.0
2.0
1.0
0.0
Density
Aim Curve
Actual
Curve
Diffuse White
1.0
2.0
3.0
Relative Log Exposure

Figure 11.

The partial success of the scanner in producing the transparencies was achieved only after a great expenditure of time. It was obvious that six good transparencies could not be produced in a reasonable time using this method. Another method was devised (see figure 12). This involved contact printing the negative of the original scene onto Kodak Fine Grain Release Positive type 7302 film (FGP). No curve shaping ability was practical, but by exposing so that a diffuse white in the scene was recorded at 0.23 above base + fog and choosing the correct combination of negative and FGP gammas a good transparency was obtained (see figure 13).

The correct gammas for the negative and FGP film are reached if the product of the two gammas equals 1.5, the slope of the aim transparency curve.

$$\gamma_{fgp} \times \gamma_{neg} = \gamma_{trans} = 1.5$$

γ_{fgp}, γ_{neg}, and γ_{trans} are the slopes of the characteristic curves for the Fine Grain Release Positive film, the negative, and the transparency respectively.

A development series with FGP (see APPENDIX) showed that a gamma of 1.8 to 1.9 was necessary in order to attain the

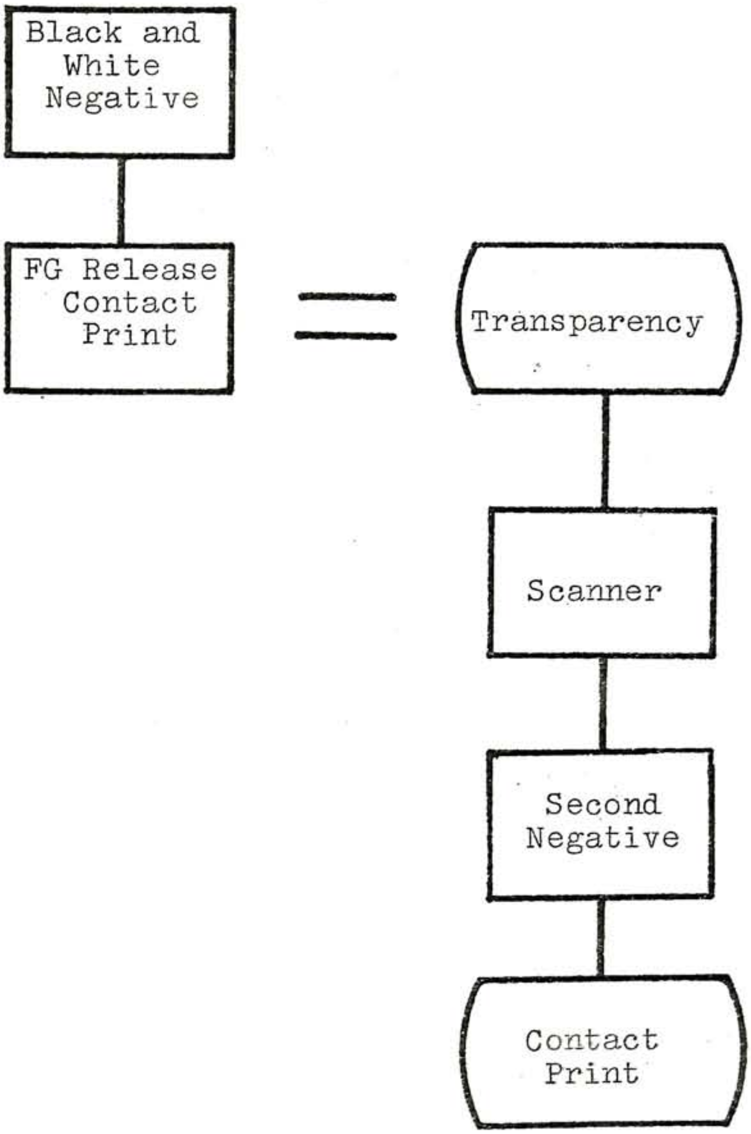

Black and White Negative
FG Release Contact Print
Transparency
Scanner
Second Negative
Contact Print

Figure 12.

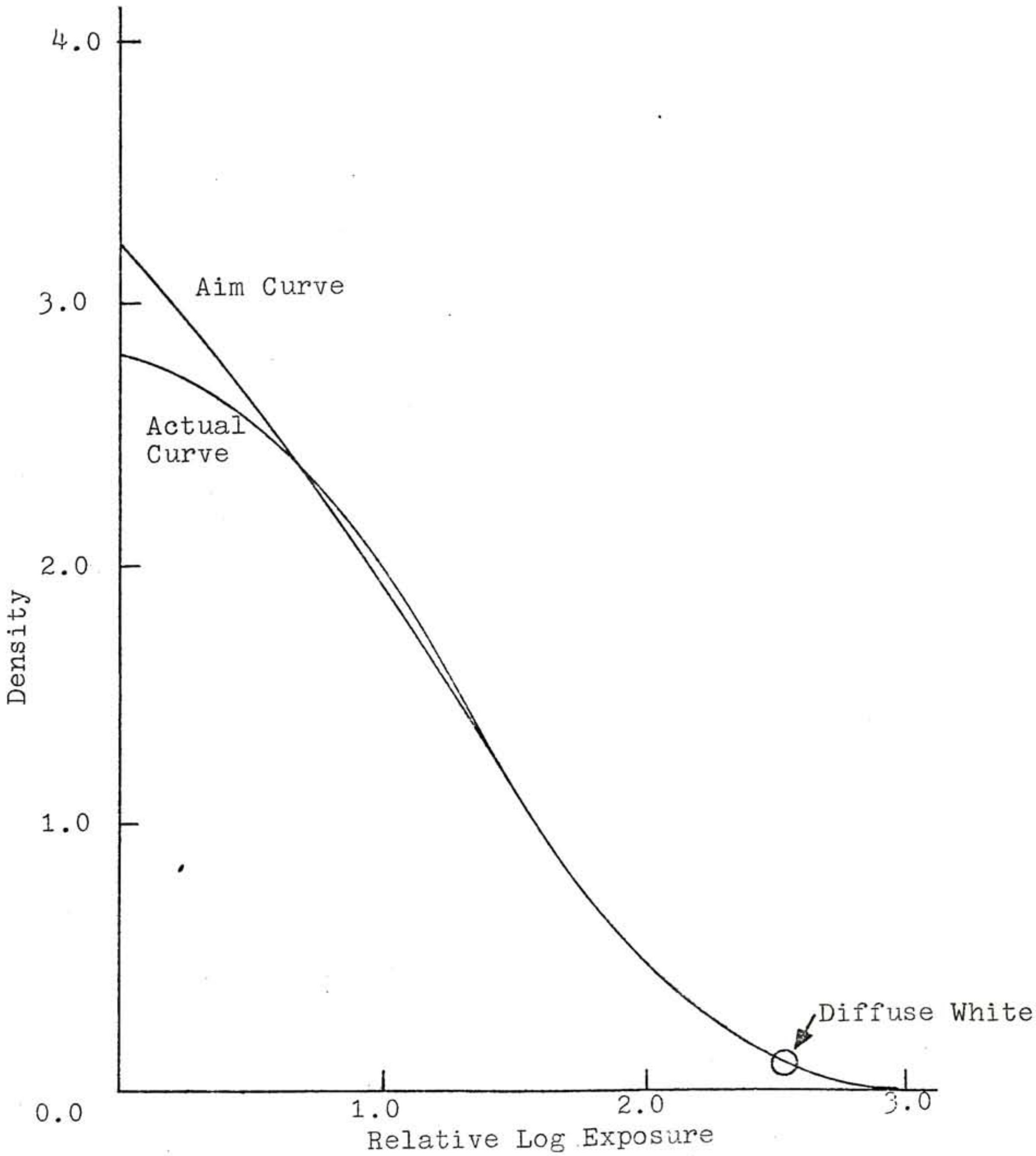

4.0
3.0
2.0
1.0
0.0
Density
Aim Curve
Actual
Curve
Diffuse White
1.0
2.0
3.0
Relative Log Exposure

Figure 13.

required density range. This meant that the gamma of the camera negative had to be approximately 0.8.

The FGP transparency was then used on the scanner in order to make the second negative needed for the desired contact reflection print. A problem encountered to a minor extent with the scanner earlier finally became a significant difficulty. The range of input densities which the scanner would accept was less than the range of densities in the transparency. With one of the operating limits at the diffuse white density in the transparency, the scanner would not control the curve shape in the shadows above a density of about 2.6. Since control over the specular highlight region was required, the control in the shadows would be reduced that much more (to approximately 2.4). This was an intriguing problem. The scanner was designed to be used with transparencies. Yet curve shaping control over densities higher than 2.4 was not available.

CONCLUSIONS

Curve A of figure 3 was the aim curve for the transparencies used in this investigation. Bartleson's and Breneman's dark surround equation predicts a relative brightness of zero for a relative density of 2.83. If the diffuse white density is 0.23 above base + fog then zero relative brightness occurs at a density of 3.06 above base + fog. Thus, relative brightness values down to zero are possible with this aim curve A of figure 4. However, we failed to question the ability of reversal transparency films in practical use to record low relative brightness values.

It was not within the scope of this investigation to adequately define the "average" characteristic curve shape for the entire family of reversal transparency films. However, it is certain that this average curve would differ from curve A of figure 4 due among other factors to the flare levels of the average camera in an average scene and flare occurring in the viewing conditions for the transparency. If one could take a large enough sample size, then the average minimum relative brightness value for practical reversal films could be specified. It would not be zero. Some data exists to support this conclusion. Nelson shows a relationship between the field luminance range and film sensitometry where the sensitometric data appears to represent a general curve shape for reversal transparencies.[17] A 2.8 maximum density (2.45 maximum relative density) is indicated. Figure 14 presents data determined by Hunt for reversal transparencies.[16] Figure 14 illustrates some important points. The crosses mark the densities actually seen by the viewers of a projected color transparency. The sensitometric curve for this commercially successful and widely used film is shown by the solid line. Nelson's data in figure 4 indicates that a gamma of 1.5

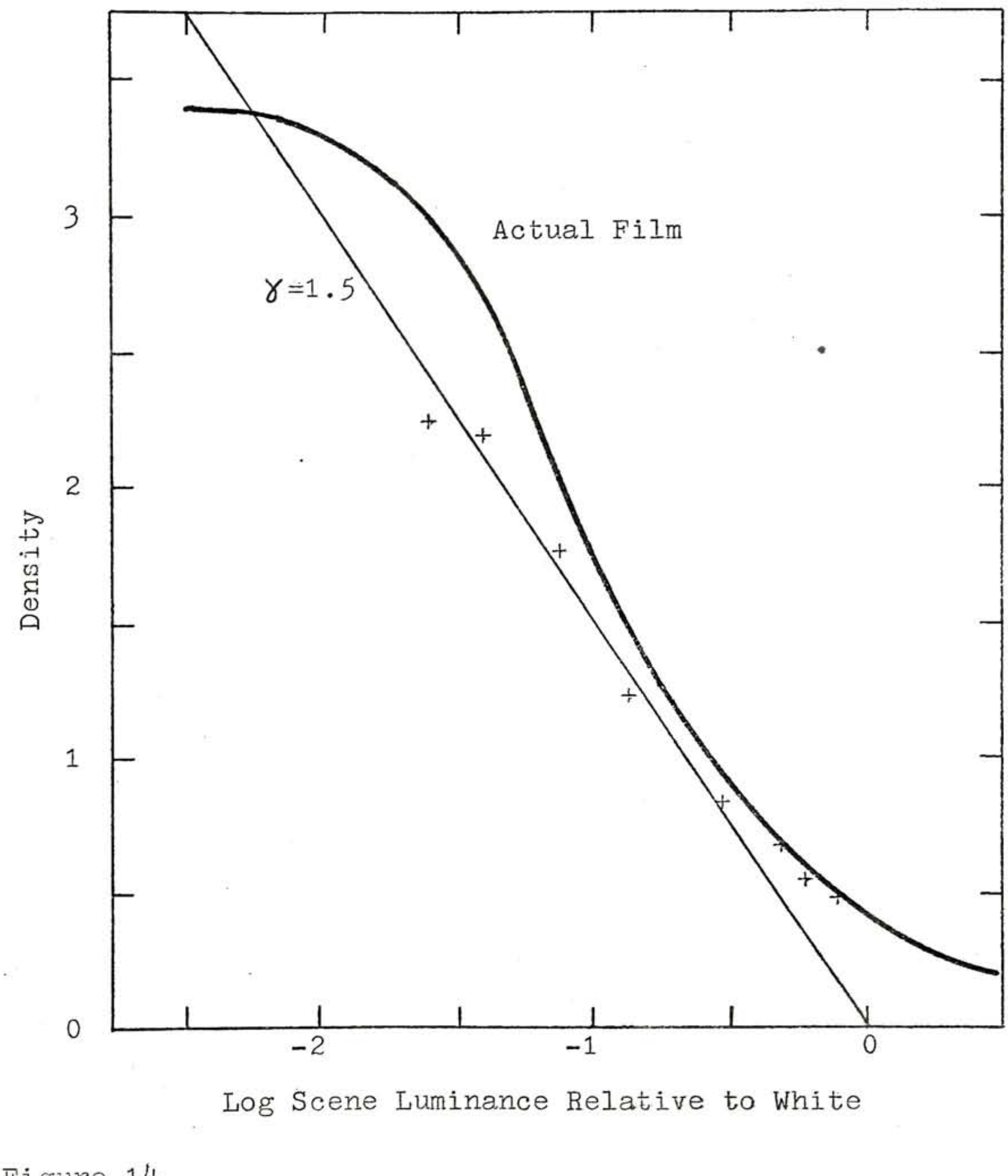


Figure 14.

* R. W. G. Hunt, <u>British Kinematography, Sound, and Television Journal</u>, 51: 268-275 (1969)

for dark surround conditions is the optimum preferred contrast. It can be seen in figure 14 that the effect of flare in the camera and projection system offsets the high gamma of the film sensitometric curve so that the net result is a transparency with a gamma of about 1.5 in the midtones. However, density values greater than about 2.3 are not present. According to Bartleson's and Breneman's dark surround equation this is a relative brightness value of approximately 10. The 2.45 maximum relative density figure indicated in Nelson's data results in a relative brightness value of about 4. This figure has not accounted for flare in the viewing conditions. The densities of five other transparency samples were read on a Macbeth TD-102 transmission densitometer. Relative densities of the deepest shadows did not exceed 2.6. This data did not account for flare in the viewing system, either. Although this is not an exhaustive or detailed analysis of the average transparency's maximum relative brightness value it indicates that transparencies found in practice do not have relative brightnesses as low as zero. Possibly, low key scenes yielding very low stray light levels in the camera might be the exception to this. However, minimum relative brightnesses in transparencies are more likely to be between 5 and 10.

Assuming that transparencies had relative brightness values down to and including zero, the departure from the 1:1 reproduction criterion with low Dmax reflection print reproductions appeared great enough to warrant a study of the compromise curve. Realizing that transparencies have minimum relative brightness more realistically between 5 and 10 it was apparent that a significant departure from the 1:1 criterion could not be isolated. This is evidence that adequate shadow reproduction for most transparencies can be accomplished by low Dmax reflection print systems. Some transparencies of very low key scenes coupled with an unusually low Dmax reflection print system would undoubtedly show discrepancies in the shadow reproduction.

Accuracy of the Relative Brightness Equations:

The accuracy of the relative brightness values predicted by equations 1) and 3) was not determined. In discussing these equations, Bartleson and Breneman did not cite any confidence limits. This series of observations was made, however:

1) The brightness scaling experimental data which the equations fit has a certain amount of variability associated with it. (This figure was not discovered in the literature)

2) The equations fit the data with accuracy no better than $\pm$ 0.5 relative brightness units. For example, a relative density of zero in equation 1) should compute an L** value equal to 100. The equation calculates a value of 99.57. Thus, all computations were rounded off to the nearest whole number in this investigation.

3) Errors in density readings on the order of $\pm$ 0.02 exist. This would cause a non linear confidence limit on the relative brightness scale. For example, at the reference white end of the scale a 0.02 error in density reading could cause a change of 3 units in the brightness calculation. A 0.02 error in the shadow areas makes neglible difference in the L** calculation.

4) Observers have more variability judging low brightness values than high brightness values.[18]

5) Because the equation set a rigid density range between the reference white and zero relative brightness, the selection of the reference white is critical in order to give zero relative brightness full meaning. Ideally, zero absolute or relative brightness should mean that the eye cannot perceive a difference between an object of zero brightness and an object with even lower luminance. The object of lower luminance would also have a brightness value of zero. Thus, one could find a relative brightness of zero in a scene by using a black hole. We suggest that by establishing the highest luminance in a scene which still appears equal in brightness compared to the black hole the correct reference white can then be calculated.

6) Equations 1) and 3) compute <u>average</u> relative brightness values. They account for the <u>average</u> effect of lateral adaptation. They do not calculate the exact effects of the surround. For example, in figure 2 the relative densities of the two circles are equal. Hence, the same relative brightness value would be calculated which would be an average of the two circles' perceived brightnesses, approximately. The variability presented by this is less than might be expected since an element in the transparency with higher or lower than average computed brightness would also be higher or lower in the print, respectively.

From the previous observations, it is obvious that the confidence limits fan out somewhat as high or low brightness values are reached. Confidence limits of $\pm$ 2 units for the midtones and $\pm$ 3 in the highlights and shadows are an educated guess on our part for the confidence limits.

With reservations about the accuracy of the brightness equations we propose a method for plotting tone reproduction in a transparency-to-print system. Working with the brightness equations is somewhat awkward to those not accustomed to them. A graph paper similar to the Munsell graph paper where density values could be plotted directly could be made using equations 1) and 3) for scaling. However, what curve results if equations 1) and 3) are used to plot the density of the print versus the density of the transparency directly on the common linear density scale? A relatively simple relationship is found. The solid line in figure 15 is this relationship. It is nearly a straight line, but it has a perceptible bow in it. If the densities of the print are plotted versus those of the transparency, 1:1 relative brightness is achieved when the curve falls on the solid line. Moreover, the dashed lines indicate how far the print is away from matching the relative brightness of the transparency. These are not confidence limits on the observers' awareness of tonal differences between the print and the transparency, of course. That is an excellent study for future investigation. No attempt has been made to draw in the curve between base + fog (0,0 on the scale) and the diffuse white point. More data on the necessary compromises in highlight and specular highlight reproduction is needed. It is possible that even the diffuse white reproduction would be found to depart from the 1:1 criterion for the optimum compromise in highlight reproduction.

We propose this curve in figure 15 for use with transparency-to-print reproductions. The linear density scale is easy and traditional,and the curve takes into account the appropriate use of the 1:1 relative brightness criterion for converting

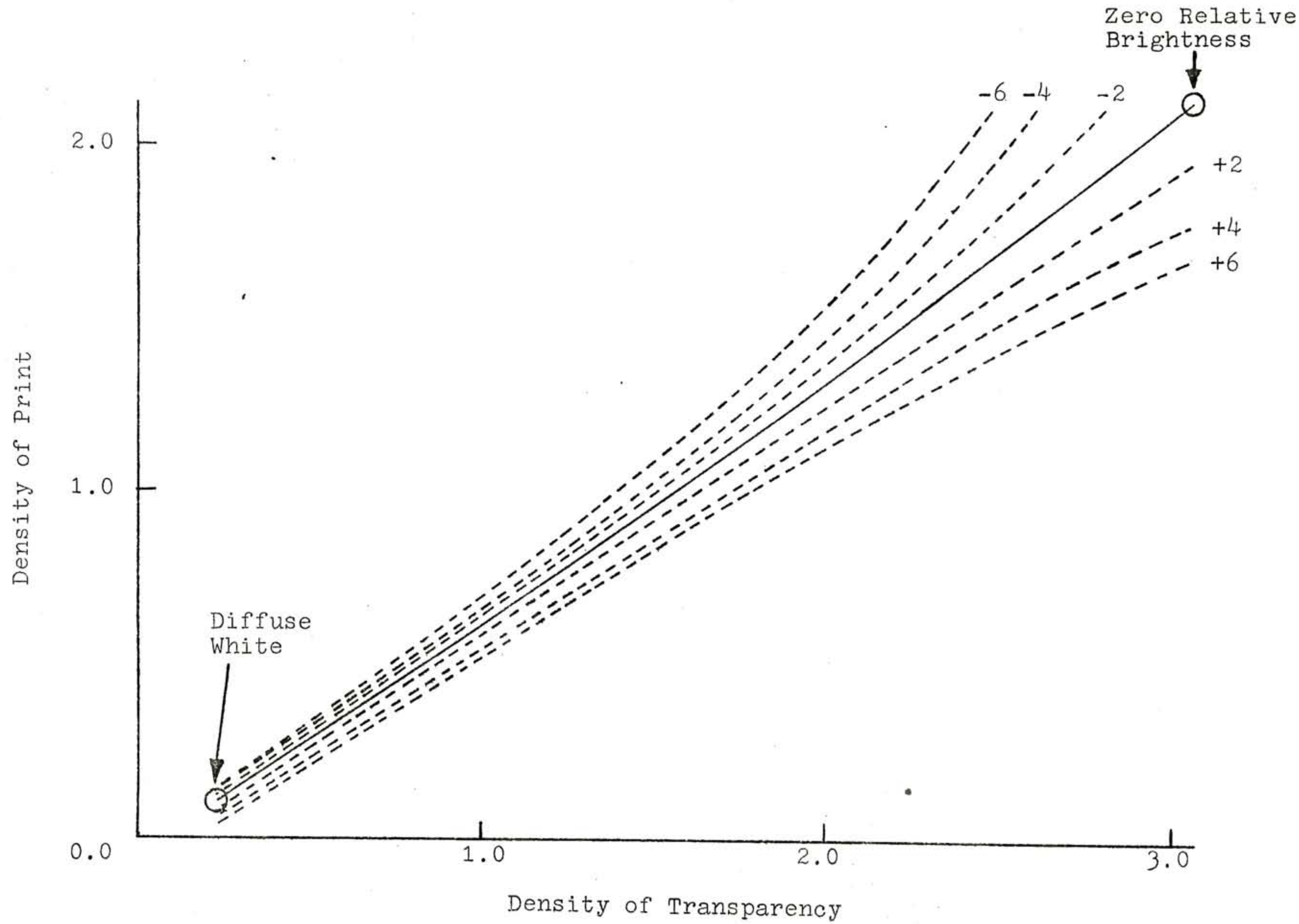

Zero Relative
Brightness
-6
-4
-2
+2
+4
+6
2.0
1.0
0.0
Density of Print
Diffuse
White
1.0
2.0
3.0
Density of Transparency

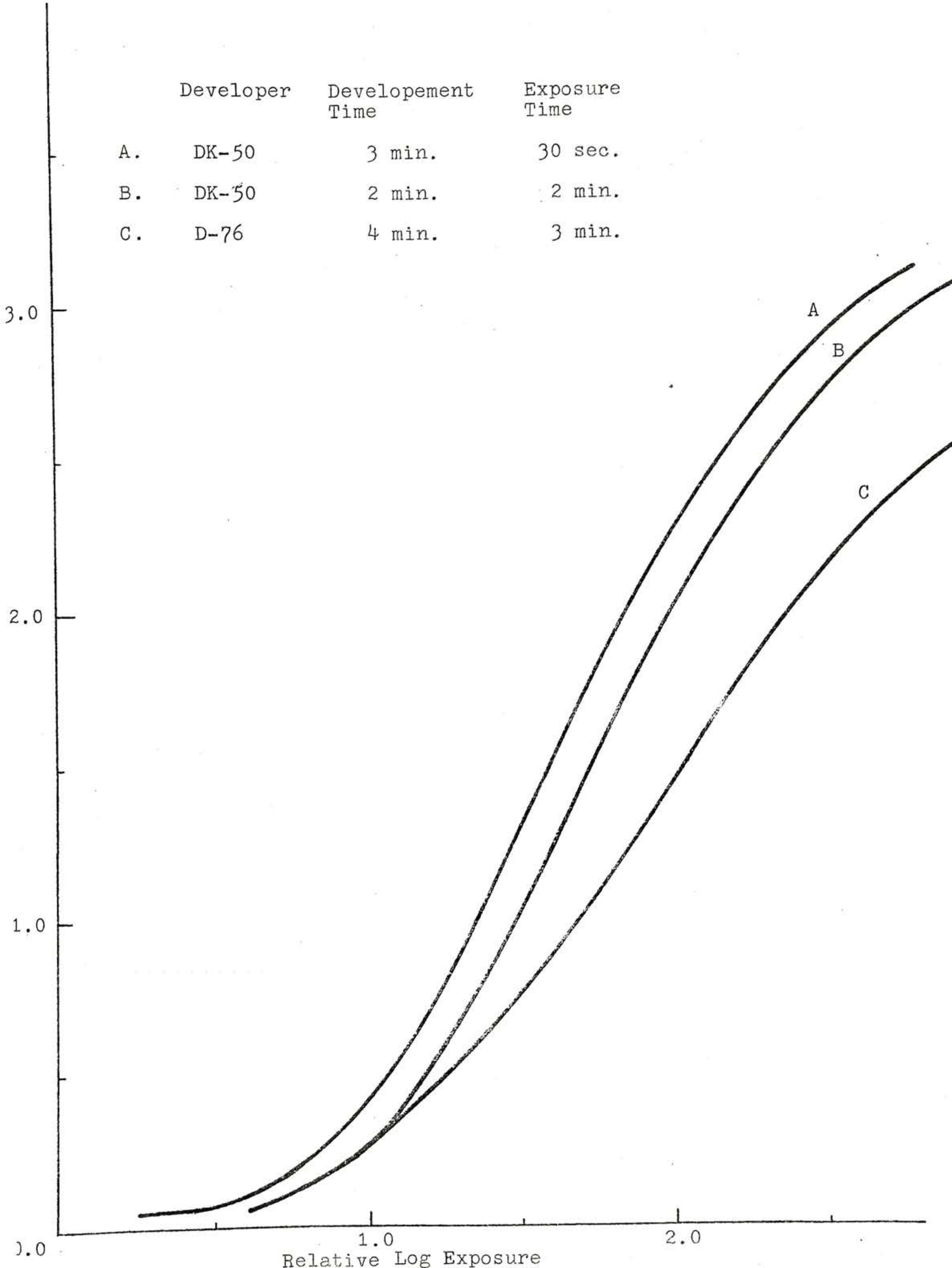
Figure 16.

transparencies to reflection prints. It is important to realize that the densities plotted on this curve (or any reproduction aim curve) should ideally be those actually seen by the observer. In other words, the flare in the viewing conditions for both the print and the transparency should be accounted for.

APPENDIX

Relative brightness, relative density values computed by equations 1) and 3)

Relative Brightness L**	Relative density of Transparency	Relative density of Print
100	0.00	0.00
95	0.06	0.04
90	0.12	0.08
85	0.18	0.12
80	0.25	0.16
75	0.32	0.21
70	0.40	0.26
65	0.48	0.31
60	0.56	0.37
55	0.65	0.43
50	0.75	0.50
45	0.85	0.57
40	0.96	0.64
35	1.09	0.73
30	1.23	0.82
25	1.38	0.93
20	1.56	1.06
15	1.76	1.20
10	2.01	1.39
5	2.34	1.63
0	2.83	2.03


Developer
Developement Time
Exposure Time
A. DK-50 3 min. 30 sec.
B. DK-50 2 min. 2 min.
C. D-76 4 min. 3 min.
A
B
C
3.0
2.0
1.0
).0
1.0
2.0
Relative Log Exposure

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